BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W.   WASHINGTON, D. C. 20024

SUBJECT: Discussion of Theoretical and
Measured Multi-Laminar Insulation
Performance Data - Case 620

DATE: December 16, 1968

FROM: J. W. Powers

ABSTRACT

All of the AAP modules are presently being designed to use some variant of multi-laminar, high performance radiation barrier insulation (HPI). Very little commonality exists between the HPI designs planned for the various modules.

A review of the performance characteristics of types of HPI planned to be used on AAP modules is presented. Correlation of predicted versus measured performance and the effects of joints and penetrations are discussed. Data comparison are complicated by the fact that no general performance index is used in the literature.

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MEMORANDUM FOR FILE

INTRODUCTION

All of the AAP modules are presently being designed
to use some variant of multi-laminar, high performance radiation
barrier insulation (HPI). Insulation design of the various
modules as presently defined exhibits very little commonality.

HPI employs the local vacuum environment and multiple,
thin, maximum-reflectance layers to achieve extremely low heat
transfer rates. With complete atmosphere evacuation, no con-
duction between N radiation barriers and the same emissivity
of all barrier surfaces, the heat transfer rate is directly
proportional to the emissivity and inversely proportional to
(N-1).

The correlation between theoretical and actual values
of heat transferred through HPI is a function of many factors
including number of layers, spacer configuration, residual gas
pressure, applied load, and method of attachment. Certain types
of HPI show almost exact agreement between theoretical and mea-
sured heat transfer rates for a few layers (<10), but increasing
conduction with an increasing number of layers.[1] This increased
heat transfer rate is caused primarily by compression and the
resultant increased number of conductive paths in lower layers
caused by the weight of upper layers.

HPI PERFORMANCE DEFINITIONS

Data correlation from the literature are complicated
by the different definitions used to report HPI performance.
The terms effective emittance, shielding factor, apparent or
effective thermal conductivity,* and heat flux are all used.
An additional performance definition, the product of density
and effective conductivity is also used. The heat flux method
of performance description requires additional information

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*Appendix A defines these terms.

relative to insulation description and test conditions. Use
of an effective thermal conductivity performance index should
be restricted to applications at the same temperatures at which
the data were determined. The problem of establishing a common
appropriate index-of-merit for HPI as reported in the literature
exists.

These performance definitions are also used to include
the effects of seams and insulation perforations, usually on
the basis of one unit length of seam or one penetration per
unit area of insulation.

HPI performance is determined by use of a calorimeter
and vacuum pump. All variables except performance index are
measured and performance index is calculated, based upon the
particular definition selected. An accurate prediction of a
performance index must consider the apportionment of energy to
both the conductive and radiative heat transfer modes. Accurate
prediction of the conduction term is highly dependent upon the
spacer configuration and deformations caused by applied loads.

HPI performance predictions involving both heat transfer
modes are the normal basis for preliminary design prior to test
verification. These first predictions can be less than precise
as some of the following data will show.

EXAMPLES FROM AAP

In an attempt to present an overview of insulation
performance, correlation between predicted and measured HPI
performance and the effects of seams and penetrations, the fol-
lowing data are presented:

LM HPI

Grumman[2] quotes the following changes in nominal
effective emissivity (0.003) for a crinkled, single-
aluminized, 0.15 mil mylar, 25 sheet basic test
panel:

- use uncrinkled barrier sheets, 16%
  degradation

- use barrier sheets with both surfaces
  aluminized, 16% degradation

- introduce a 12-in. long, 6-in. wide
  overlap joint per ft^2 HPI, 37% degra-
  dation

- introduce a 12-in. long, 2-in. wide
  folded seam per ft^2 HPI, 33% degradation

. introduce a penetration for a fiber-
glass standoff retainer, 53% degra-
dation for one penetration per ft^2 HPI.
With a low emissivity coating on the
fiberglass support, degradation is
reduced to 28%.

CM-SM HPI

North American Rockwell quotes a 0.02 design
emissivity for the NRC-2 type HPI. This value
appears to be confirmed by thermal vacuum test
2TV-1. Approximately 25% of the system makeup
heat is lost through structural penetrations.[3]
Reference 3 also states that the results of the
first LM test yielded an effective emittance of
0.016. After insulation redesign and LM retesting,
the effective emittance was reduced to 0.011. The
significant variation between the above LM values
and the 0.003 effective emissivity of Reference 2
is caused by the differences of a complex, multiple
penetration, complete system test as compared with a
simple test panel.

MDA HPI

MSFC reports a design thermal conductivity of
5×10^{-4} BTU/hr-ft$^{\circ}$R for the MDA HPI.[4] Current
contractor measured effective thermal conductivity
is 1×10^{-4} BTU/hr-ft$^{\circ}$R at a mean temperature of
75°F.[5] MSFC thinks this 5:1 ratio between design
value and calorimeter data is an appropriate "rule
of thumb" safety factor for space vehicles utilizing
HPI.[5]

Goodyear Aerospace has proposed a pair of rectangular
hyperbolas to describe the effect of joints on the
effective thermal conductivity of the MDA insulation.[6]
These equations are

$$(A/L) \ (\overline{K} - 3.8 \times 10^{-5}) = c$$

where A/L is the ratio of panel area to joint length,
$\overline{K}$ is effective conductivity, and c is a constant
(3.69×10^{-5} and 5.86×10^{-5}). The conductivity for
no joint is the asymptotic value 3.8×10^{-5} BTU/hr-ft$^{\circ}$F.
The average of these two equations yields a 125% in-
crease in effective conductivity for a linear foot of
joint per square foot of insulation.

MDA AND ATM HPI

Convair Division of General Dynamics has conducted
an MSFC sponsored program to test the MDA and ATM
insulation.[7] The ATM insulation is a modification
of the National Research Corporation, NRC-2 material.
The predicted heat flows for the NRC and NASA HPI were
0.489 and 0.337 BTU/ft^2-hr. The respective measured
values were 0.30 and 0.17. After adjustment of the
method of predicting the conduction term, later tests
showed much better agreement with the calculated value
being 5% greater than the measured value.

J. W. Powers

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Attachment
  Appendix A

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References

1. Glaser, P. E., et al, "Thermal Insulation Systems," NASA SP-5027, 1967.

2. Bartilucci, A., et al, "LM Passive Thermal Design and Test," AIAA Paper 68-748.

3. "Apollo Applications Program CSM Configuration Baseline, Supporting Data," SD 68-558, North American Rockwell Corporation, October 7, 1968.

4. "Data Package, Multiple Docking Adapter," MSFC, R-P&VE-PMD, December 14, 1967.

5. Personal Communication, E. H. Hyde, R-P&VE-PT, MSFC, December 4, 1968.

6. Burkley, R. A., et al, "Development of Materials and Materials Application Concepts for Joint Use as Cyrogenic Insulation and Micrometeoroid Bumpers," Annual Report on Contract NAS 8-11747, Goodyear Aerospace Corporation, June 30, 1968.

7. Getty, R. C., "Cryogenic Insulation Development," Final Report on Contract NAS 8-18021, Convair Division, General Dynamics, January 1968.

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Appendix A

HPI Performance Definitions

To define effective thermal conductivity ($\overline{K}$) and effective emissivity ($\overline{\epsilon}$), the following symbols are used:

- a – Insulation Thickness
- N – Number of Radiation Barriers
- Q – Heat Flow Rate per Unit Area
- T – Temperature
- ϵ – Emissivity of Both Barrier Surfaces
- σ – Stefan-Boltzman Constant

If a conduction definition for the radiative-conductive process in multiple-layer insulation is used, effective thermal conductivity is

$$\overline{K} = \frac{Qa}{T_2 - T_1}$$

Effective emissivity is defined from the Stefan-Boltzman fourth power law

$$\overline{\epsilon} = \frac{Q}{\sigma(T_2^4 - T_1^4)}$$

For the limiting case with no conduction heat transfer occurring in the insulation, $\overline{\epsilon} = \epsilon/(N-1)$.

If the temperature difference is small, a simple approximate relationship between $\overline{\epsilon}$ and $\overline{K}$ is found by eliminating Q.

$$\overline{K} \approx (4\sigma a T^3)\overline{\epsilon}$$

In HPI which does not utilize separate spacer components, the emissivities of the two barrier surfaces are not equal because only one surface is aluminized. The limiting effective emissivity with this configuration is

$$\bar{\epsilon} = \left(\frac{1}{N-1}\right) \frac{\epsilon_1 \epsilon_2}{\epsilon_1 + \epsilon_2 - \epsilon_1 \epsilon_2}$$

If the product of density and effective thermal conductivity is $\rho\bar{K}$ and the unit weight per barrier layer including any spacer is w,

$$\rho\bar{K} = \frac{QNw}{T_2 - T_1}$$

The number of barrier layers per unit thickness of insulation is N/a.

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Insulation Performance Data

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